Technical Dialogue

by John S. Nordin, Ph.D.

COMMON SENSE CORRECTIONS TO AIR DISPERSION MODELS FOR TOXIC CHEMICAL RELEASES

Why are corrections needed?

The air dispersion models predict downwind average concentrations as a function of distance from the release. The user specifies information on the release strength (e.g. kilograms/minute), basic meteorology (wind speed, cloud cover, time of day, etc.), and the distance downwind; the model then predicts the concentration at that location. The PEAC tool does the same basic calculations except that the user specifies a concentration representing a level of concern, and the PEAC tool calculates the distance downwind corresponding to that level of concern.

The problem is that the real world is more complicated. The wind speed and direction fluctuate even on a second-by-second basis. Very complicated wind patterns occur as the wind interacts with buildings and with terrain. The sun heats the ground during the day causing the air near the ground to rise resulting in turbulent or unstable air conditions. Many air toxic releases are finely divided particulate matter or an aerosol (e.g. from an explosion, fire, or even a hole in a tank or pipe under pressure) rather than a gas. These particulates or aerosols can partly deposit and contaminate surfaces as they travel downwind. Even after the plume cloud containing the toxic chemical has passed, there may still be residual pockets of contaminated air in crevices, ditches, or even inside buildings.

Air dispersion models that use mathematical algorithms to predict downwind concentrations cannot deal with these complications except in a very rudimentary way. Even if the mathematics could be developed, the model would ask the user to input very detailed information on the situation and terrain. The user probably would not have available this information.

Much more useful is for the model to ask the user very basic information that is easy to understand. The air dispersion model then calculates an estimate of the downwind concentration as a function of distance (or calculates the distances corresponding to different downwind concentrations). This is helpful in predicting evacuation distances and safe entry after an incident. The emergency responder should be aware of situations and common sense rules that result in higher concentrations than predicted by the air dispersion models and take the necessary precautions.

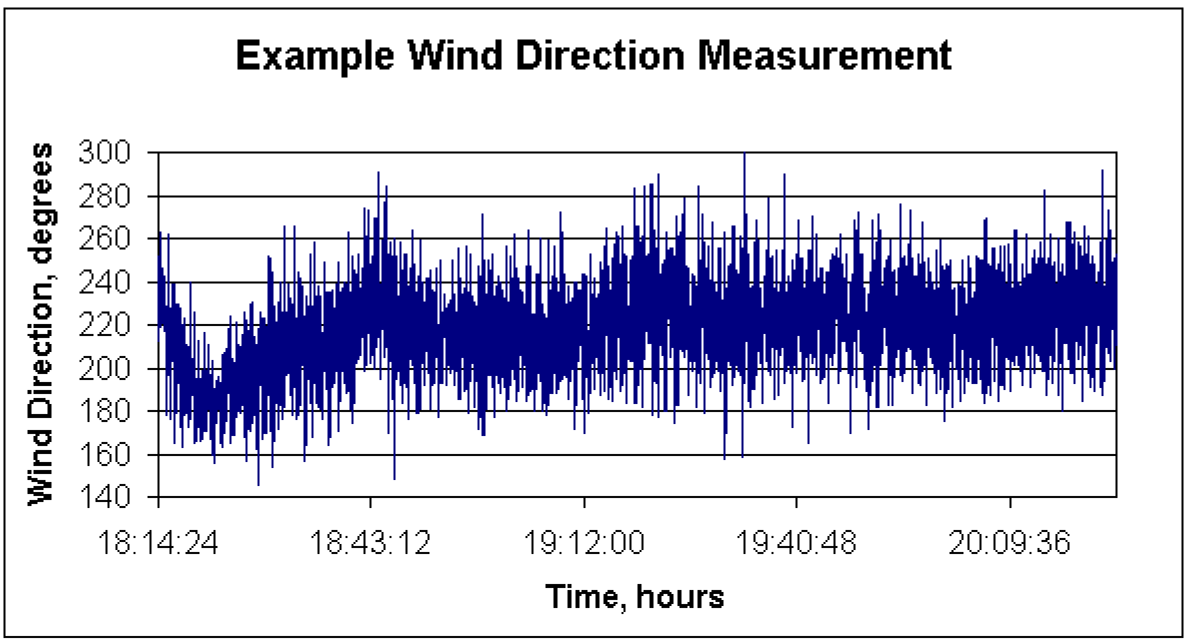
Let us look at some of these situations that can result in higher concentrations than predicted by toxic gas dispersion models.

Fluctuating Wind Conditions and Air Toxic Concentrations

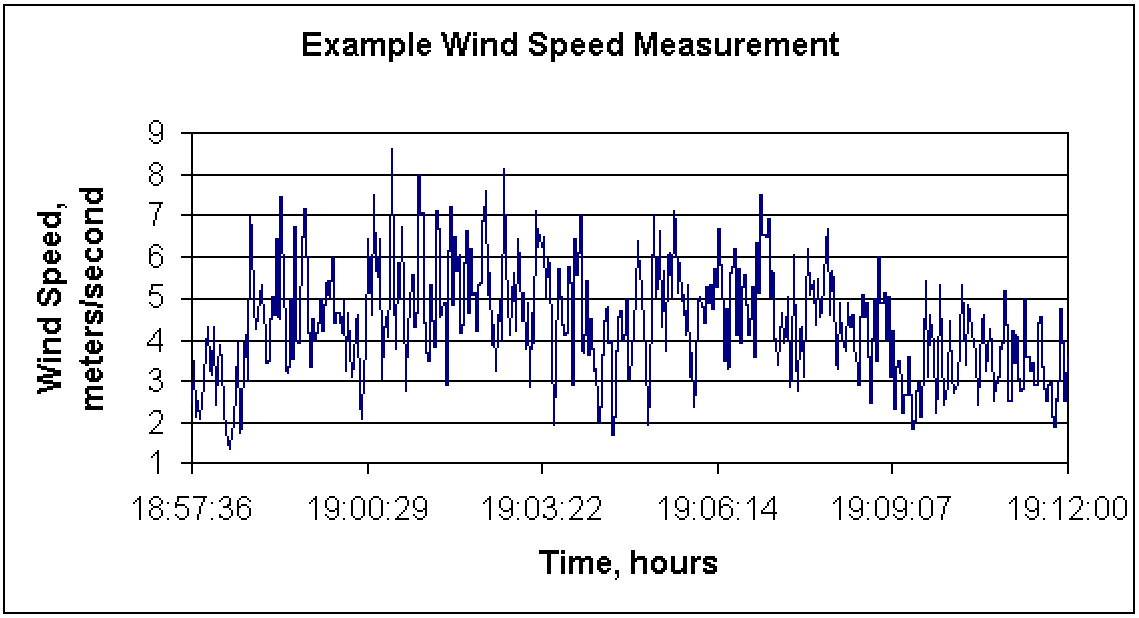
Imagine a situation where a toxic chemical is released at a constant rate at ground level. The prevailing wind is from the southwest at a fairly constant speed. The terrain is flat. The wind is strong enough and conditions are later in the day so we won’t have to worry about the air turbulence resulting from ground solar heating. Now imagine that we have placed instrumentation to measure air speeds and directions at many locations and heights downwind and upwind of the toxic chemical release point. We have also done the same with chemical sensors, placing them at various heights and locations downwind, crosswind, and even a few upwind of the release point. What would we find? What would data from all this instrumentation look like?

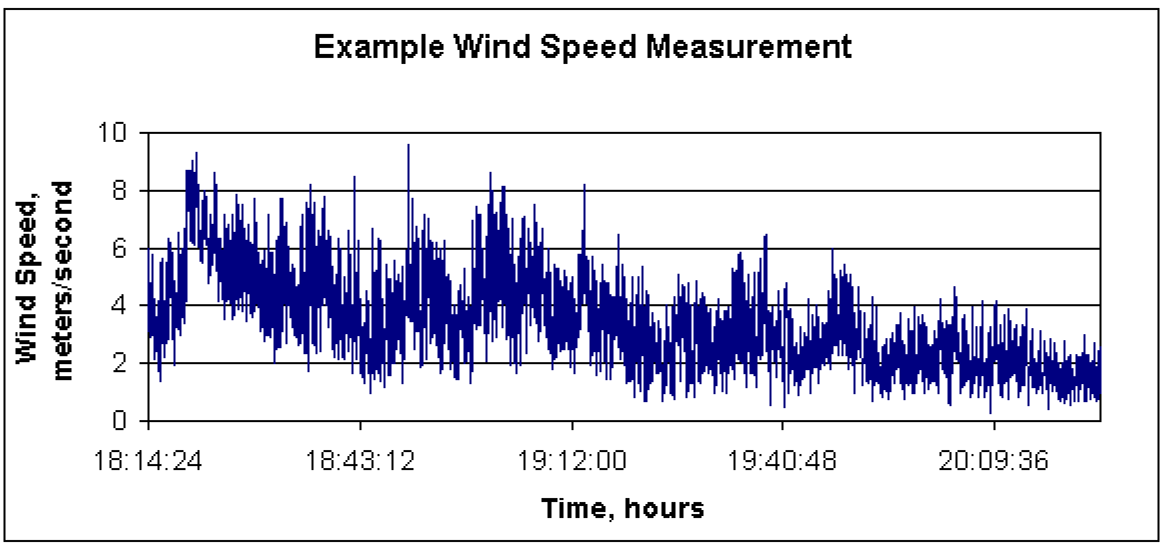
The August-September 1995 series of tests (called "Kit Fox") performed at Frenchman's Flat at the Department of Energy Haz Mat Spill Center northeast of Mercury, Nevada, did just that. Carbon dioxide was used as a surrogate for a toxic chemical release; the chemical sensors were corrected to measure only the carbon dioxide concentration above background. Close to 100 tests were performed under a variety of meteorological conditions ranging from daytime steady wind conditions to near nighttime conditions when the winds have for all practical purposes ceased. The releases varied from short 15-second puffs to steady constant releases lasting many minutes. Some of the tests were done with plywood structures representing buildings in the path of the carbon dioxide plume as it traveled downwind. These tests were sponsored in part by DOE, EPA, and by 10 petroleum and chemical companies.

If the data from any of these wind or carbon dioxide measuring sensors are plotted over time, there are considerable fluctuations, as seen in the examples below.



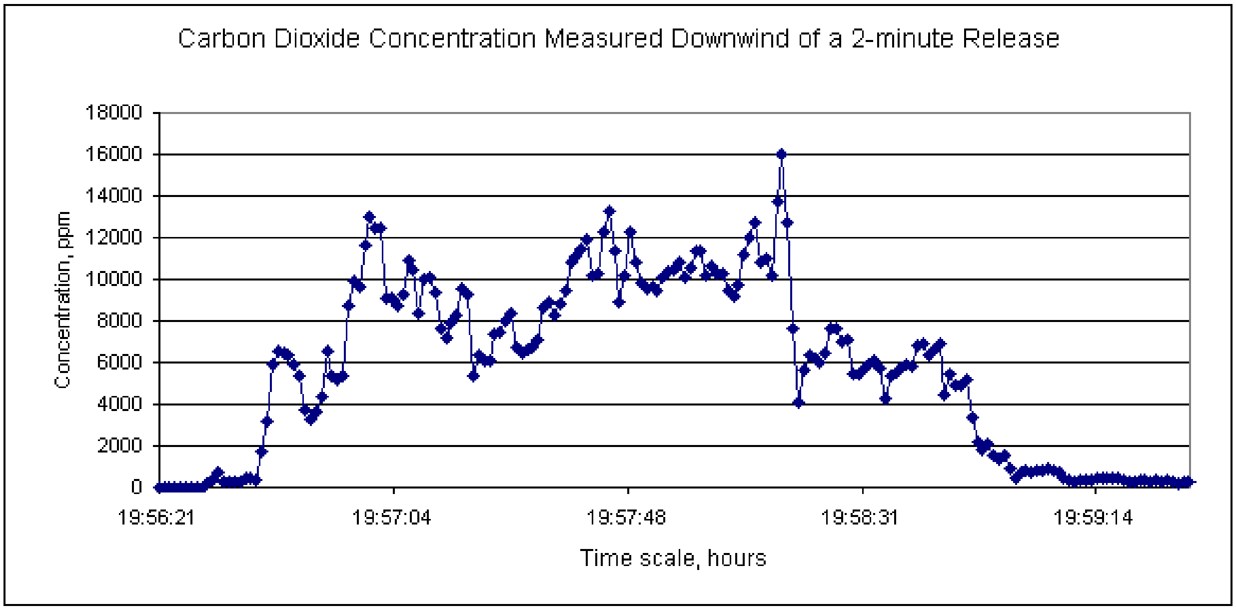
For the example presented, the wind sensor was placed two meters above the ground. The time represents hours since midnight (standard time) on August 28, 1995. Data was recorded at one-second intervals





The graphs show considerable fluctuations of wind speed and direction with time. The third graph is a 15-minute blowup of a section of the second graph which expands 3 hours.

These fluctuations were not unique to the sensors used or for the date of the measurements. All wind sensors showed fluctuations. Measurements taken at other locations by other organizations also show similar fluctuations. If sonic anemometers are used to record data, fluctuations on a very small time scale can be seen.



A lot of factors influence the magnitude of fluctuations. These include the degree of solar heating or ground cooling, the terrain, presence of buildings and other structures, the height at which the wind is measured, and weather.

Now let us see what happens if we release 1.50 kg/sec of carbon dioxide at ground level for two minutes into the atmosphere. A sensor measuring the carbon dioxide concentration downwind of the release point might yield a time plot as shown above. For these tests, about 90 carbon dioxide sensors were employed at various locations; this is an example. The average concentration as seen by the sensor was about 9000 ppm carbon dioxide (ignoring the initial buildup and tail-off at the end), but because of wind fluctuations and extent of mixing into the air, the instantaneous concentration was as high as 16000 ppm.

In addition to small-scale fluctuations in concentration, the toxic cloud can meander in and out of the centerline location. In the example shown above, the cloud centerline meandered away from the sensor resulting in lower concentrations towards the end of the two-minute release period. Also, the duration of the cloud as it passed over the sensor was somewhat longer than two minutes. The cloud tends to spread out laterally, horizontally, and vertically as it travels downwind.

The gas dispersion models in the public domain including the models in the PEAC tool predict average concentrations and do not predict spikes or peak concentrations. Peak concentrations are of most concern when dealing with highly toxic chemicals where one or two breaths may be fatal or incapacitating. Meander can be corrected by assuming that the highest concentration passes over the receptor, e.g., the worst case. The PEAC tool assumes that the toxic cloud has "meandered" such that the highest concentration is at the protective action distance downwind of the release. However the models in the PEAC tool (and also ALOHA, SLAB, and other models) do not consider fluctuations, where "slugs of toxic chemical" might pass over the receptor. Some models ask the user to specify a term called the “concentration averaging time”; if the user specifies a short averaging time (e.g. one minute), the model will predict higher concentrations at the cloud centerline. A long time (e.g. 1 hour) specified would predict a lower concentration because of normal meander. However concentration spikes occurring because of localized wind shifts and eddies formation are not predicted.

<u>What Happens if the Winds Die Down Completely?</u>

A test at the DOE Haz Mat Spill Center (part of the Kit Fox series of tests performed during August and September 1995) fit this weather condition. Carbon dioxide was released at ground level at a constant rate for a period of 6 minutes under almost nighttime conditions and clear skies. The winds, which were about 1 meter per second at the start of the test, essentially quit at the end of the test. The carbon dioxide pooled over the ground and remained there during the night. But there were still considerable concentration fluctuations as the air slouched around the measuring sensors.

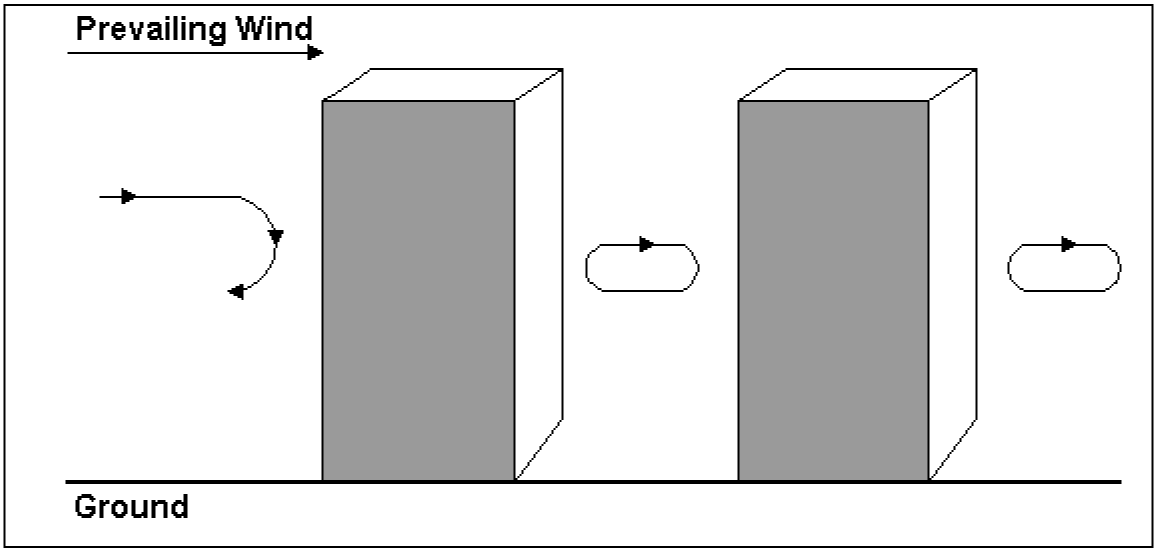
Chlorine was released through windows from a building at Springfield MA one June evening about 13 years ago as a result of an accident. Weather conditions were overcast, with no wind at all. Residences in the area within a few miles of the release site reported chlorine odors during the night, and evacuations took place. There was no correlation between elevation or direction from the source. The chlorine gas apparently skipped around with no apparent pattern. Chlorine odors were present at some locations far from the site and absent at closer locations.

<u>The Urban Environment</u>

Most models including the models in the PEAC tool allow the user to either input a surface roughness length or select between choices of (1) flat, open terrain, (2) cropland or light residential, or (3) urban or forest conditions. The effect of buildings and other structures is to help break up and disperse the toxic chemical cloud as it travels downwind. Therefore the toxic cloud is wider, higher, but less concentrated at the centerline than if it passed over a flat surface.

Plywood structures simulating buildings were placed in the path of the plume cloud for the carbon dioxide release tests as part of Kit Fox (August-September 1995 tests in Nevada). The tests verified that the plume cloud was taller and wider compared with flat terrain because the structures tended to break up the cloud. But the tests also demonstrated many anomalies. These included (1) parts of the carbon dioxide cloud traveling upwind, (2) a taller carbon dioxide cloud than predicted by models, (3) sometimes higher concentrations measured at several meters above the ground than at the ground surface, and (4) a long time to scour out the residual carbon dioxide from the structures after the cloud passed. Some of these anomalies could also be demonstrated in a wind tunnel, but the wind tunnel could never simulate the large-scale tests outdoors under stable, nighttime conditions (the so-called “F” stability).

Gas dispersion models predict average conditions. They do not predict peak concentrations because of wind fluctuations or anomalies because of wind patterns around buildings. Some anomalies are as follows:



- The local wind conditions may not match the prevailing wind because of circulation patterns induced by buildings. In the case of a toxic chemical release, concentrations can build up between buildings and take a long time to flush out.

- Recess entryways to buildings, alcoves, and ditches or recessed areas can trap and hold air toxics for some time since the general toxic plume cloud has passed.

- The air toxic can move short distances against the prevailing wind direction along the sides, the top of the building, and even in front of the building.

- The prevailing wind may switch direction and even reverse itself occasionally. The peak concentration in a cloud may easily switch from one side of a building to another in seconds.

- If the prevailing wind is parallel to streets bordered by tall buildings, the toxic plume cloud might be basically contained within the street canyon, but there will be some cloud travel along side streets. If the prevailing wind is diagonal to the streets, the plume cloud can get channeled by streets near the source and wind up traveling off the prevailing wind direction axis.

- Generally it is safer to remain inside buildings in case of a toxic chemical release. However, after the plume cloud has passed outdoors, it may be safer to move outdoors because of residuals that have entered the building because of ventilation and remained onside. Obviously there are overriding situations such as danger of fire or explosion or if residual radioactivity or biological agents have been deposited on surfaces.

- Some contaminants may stick to surfaces. Touching surfaces in the vicinity of the release point is not recommended until decontamination is complete.

More information on “rules-of-thumb” corrections for air toxic releases in urban environments is discussed in the following paper published by the Los Alamos National Laboratory:

Brown, Michael J. and Gerald E. Streit. 1998. “ Emergency Responders’ “Rules-of-Thumb” for Air Toxic Releases in Urban Environments”. Los Alamos National Laboratory report LA-UR-1998-4539.

A copy of this paper can be obtained by visiting the website, http://www.mipt.org/pdf/la-ur-98-4539.pdf